METHOD FOR CALIBRATING A TOOL CENTER POINT OF TOOLS FOR INDUSTRIAL ROBOTS

The invention relates to a method for calibrating a tool center point of tools for industrial robots comprising a calibration apparatus that has at least two light barriers which are angled to one another with a vertex angle α greater than zero in each case and cross one another at a crossing point, exhibiting the steps of:

a) fixing ACTUAL TCP positional coordinates of a DESIRED tool center point of the tool with reference to a tool reference point of an industrial robot, and to a TCP coordinate system referred to the tool center point, and

b) moving the tool with reference to the TCP coordinate system through the light barriers such that the tip of the tool corresponding to the tool center point interrupts the light barriers.

In order to approach any desired points within a working space, industrial robots have a number of interconnected arms, a hand flange at the end of the last arm of the mutually concatenated arms, and a tool that is fitted on the hand flange. The tool can be, for example, a gripper, a welding head or the like.

The position and orientation of the hand flange or the tool center point of a tool fitted on the hand flange can be specified in a stationary robot-independent world coordinate system, or in a stationary base coordinate system referred to an anchor point of the industrial robot. By contrast, the description of the position of the degrees of freedom, that is to say axes and the hand orientation, is done in robot coordinates, wherein starting from the principal axis of the robot,

that is to say of the base coordinate system, there is defined for each arm an robot axis coordinate system that describes the relative position of each axis with reference to its preceding axis. The relationship of

5 the robot axis coordinate systems of an industrial robot is described by defined coordinate transformations. By prescribing the position and the orientation of the hand flange or of the center point of a tool in the world coordinate system, it is

10 therefore possible by means of coordinate transformation to calculate the robot axis coordinates in order to be able to drive the individual axes of the industrial robot.

15 The position of a center point of a tool that is fitted on the hand flange of the industrial robot is described by means of so-called TCP positional coordinates. The programming of the industrial robot is performed on the basis of the hand flange and the fixed TCP positional

20 coordinates. The TCP positional coordinates are supplied along with each tool and are known as tool center point (TCP). Just like the robot axis coordinates, the TCP positional coordinates are in each case a vector with six dimensions. The first three

25 coordinates define the position of the tool center point relative to the tool reference point of the industrial robot, that is to say the fastening point on the tool on the hand flange. The other three coordinates define the orientation of the axis of the

30 tool center point relative to the tool reference point.

The center point of the tool can be, for example, the tip of a welding head. The center point of the tool can be moved precisely only once the TCP positional

35 coordinates are exactly known.

However, during operation the center point of the tool can change owing to tool wear, bending etc., and this

leads to defective positioning of the center point of the tool.

There is thus a need to calibrate the center point of tools with high precision.

EP 0 417 320 A1 describes a method for calibrating the center point (TCP) of the tool of an industrial robot in the case of which a setting point is fixed on the hand flange of the robot arm, the position of the setting point relative to the hand flange being known. Furthermore, a reference tip is set up in the working space of the industrial robot. In order to calibrate the tool center point, the tip of the tool is placed on the reference tip, and the position and orientation of the tool tip is determined in a base coordinate system. The setting point of the hand flange is then placed on the reference tip, and the position and orientation of the setting point is determined in the coordinate system of the hand flange. In addition, the position and orientation of the reference tip is determined in the reference coordinate system, and a transformation matrix is calculated from three matrices for the purpose of designating the TCP positional coordinates of the tool center point of the tool.

The calibration requires a multistage movement operation as well as coordinate transformations.

US patent 6,352,354 B1 describes a light point element for generating a light point signal at a tool center point of an industrial robot. It is possible thereby to describe the exact position of the tool during a learning phase.

US patent 5,929,584 describes a method for calibrating a tool center point of tools with the aid of a calibration block that has vertical and horizontal surfaces. The TCP positional coordinates of the tool

center point are calculated by moving the tool from a starting position up to a contact position of the tool on one of the surfaces, and moving the tool back to the starting point and repeating the operation for the
5 other surface. This disadvantageously requires a complicated coordinate transformation from the reference coordinate system via the individual robot coordinates up to the hand flange, in order to determine the TCP positional coordinates in the TCP
10 coordinate system from the reference coordinates.

DE 37 24 656 T2 describes a multidimensional measuring machine with fork light barriers which meet at a crossing point. Because of the plurality of light
15 barriers, which all lie in the same plane, it is possible to scan the tool in a contactless fashion from different directions but in the same scanning plane.

US patent 5,177,563 discloses a fork light barrier for
20 calibrating a robot arm in which the tool tip is moved until the latter lies at the crossing point of the light barriers and two light barriers are triggered simultaneously. The TCP positional coordinates at this crossing point are compared with DESIRED TCP
25 coordinates and a deviation is determined therefrom. However, searching for the crossing point is wearisome.

It is therefore an object of the invention to provide an improved method for calibrating a tool center point
30 of tools for industrial robots.

The object is achieved according to the invention with the aid of the generic method by means of the further steps:
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    c)   recording ACTUAL TCP positional coordinates upon the interruption of a respective light barrier,

d)   determining the differences between the DESIRED
        TCP positional coordinates for the interruption of
        the light barriers at a DESIRED tool center point
        and the corresponding recorded ACTUAL TCP
        positional coordinates for the ACTUAL tool center
        point, and

e)   calculating the deviation of the ACTUAL tool
        center point from the DESIRED tool center point
        for the number of planes that is prescribed by the
        light barriers from the differences and the known
        position and vertex angles α for the light
        barriers.

It is therefore proposed from the known plane defined
by the light barriers and the at least one vertex angle
α the deviation of the ACTUAL tool center point from
the DESIRED tool center point from the ACTUAL TCP
positional coordinates for each axis of the coordinate
system, which are fixed in each case upon interruption
of a light barrier, in order to calculate onto the
deviation of the tool center point for individual axes
of the coordinate system. This eliminates the search
for the crossing point in determining a tool center
point. Rather, the robot can be moved into the
calibration apparatus as if the DESIRED tool center
point is to be reached directly by the tool tip. The
deviations of the tool center point can then be
determined from the temporally offset interruptions,
occurring in the event of the displacement of the tool
center point, of the individual light barriers, the
orientation of which exhibits a relationship with the
coordinate system of the industrial robot.

It is advantageous when subsequently the TCP positional
coordinates are corrected by the calculated deviation
of the ACTUAL tool center point from the DESIRED tool
center point for the planes of a coordinate system, on
which the TCP positional coordinates are based.

It is also particularly advantageous when the DESIRED tool center point is fixed with the aid of the TCP positional coordinates in the case of which the tool tip corresponding to the tool center point simultaneously interrupts all the light barriers at a common crossing point.

The invention becomes plainer with the aid of an advantageous embodiment in the case of which two light barriers are provided that cross one another at a vertex angle α of 90° and define a first plane of a coordinate system, the first light barrier corresponding to a first axis y, and the second light barrier corresponding to a second axis z of the coordinate system.

On the basis of the defined assignment of the light barriers to the first and second axes, the deviation of the tool center point can be determined for the first axis from the deviation, determined upon interruption of the first light barrier, of the ACTUAL tool center point from the DESIRED tool center point, and the deviation of the tool center point for the second axis can be determined from the deviation, determined upon interruption of the second light barrier, of the ACTUAL tool center point from the DESIRED tool center point.

If the TCP positional coordinates that are determined upon interruption of the light barriers are described in the same coordinate system, depending on tool bending, upon, for example, interruption of the first light barrier, the deviation of the y coordinate of the TCP positional coordinates would be determined, and upon interruption of the second light barrier the deviation of the z coordinate of the TCP positional coordinates would be determined and, if appropriate, the TCP positional coordinates would be appropriately corrected.

The invention is explained in more detail below with the aid of the attached drawings, in which:

5   figure 1   shows a perspective view of a calibration apparatus according to the invention having two mutually crossing light barriers;

     figure 2   shows a plan view of the calibration
10   arrangement according to Figure 1;

     figure 3   shows a sketch of an industrial robot having a number of arms and a base coordinate system as well as axial coordinate systems; and

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     figure 4   shows a sketch of the displacement of the center point of a tool after wear with reference to a TCP coordinate system.

20   Figure 1 shows a calibration apparatus 1 according to the invention in a perspective view. The calibration apparatus 1 has a frame 2 that is open on one side and has two parallel limbs 3a, 3b spaced apart from one another. The calibration apparatus 1 is therefore U-
25   shaped. The limbs 3a, 3b are integrally connected to a holding plate 4 with the aid of which the calibration apparatus 1 can be mounted in a stationary fashion in the working space of the industrial robot.

30   Provided in the limbs 3a, 3b are light barriers 5a, 5b that are aligned diagonally thereto and run up to one another at a vertex angle α of 90° and meet at a crossing point R in the interspace between the limbs 3a, 3b. To this end, in each case a transmitter 6 and
35   one receiver 7 per light barrier 5a, 5b is fitted at a front end of a first limb 3a and at the rear end of the other limb 3b for the first light barrier 5a, and at the rear end of the first limb 3a and the front end of the second limb 3b for the second light barrier 5b.

This results in the creation of a fork light barrier that is preferably designed as an infrared light barrier.

5   Figure 2 shows the calibration apparatus 1 in plan view. It is plain that the light barriers 5a, 5b run diagonally between the limbs 3a and 3b and meet in the interspace of the limbs 3a, 3b at the crossing point R.

10   A center point TCP of a tool for an industrial robot, for example, the tool tip, is moved for the purpose of calibrating the tool center point TCP so as to approach a DESIRED tool center point $TCP_{DESIRED}$ that preferably lies at the crossing point R of the calibration
15   apparatus 1. In this case, both light barriers 5a, 5b are interrupted by the tool tip such that a switching signal is generated.

The calibration method is explained in more detail
20   below.

Figure 3 shows a sketch of an industrial robot 8. An industrial robot 8 has a base coordinate system $\tilde{O}_0$ or world coordinate system that is aligned in a stationary
25   fashion with reference to the foundation of the industrial robot 8. Located on the base 9 is a chain of arms 11 interconnected via joints 10. Defined for each of these arms 11 is an axial coordinate system $\tilde{O}_1$, $\tilde{O}_2$, $\tilde{O}_3$ with the aid of which the position and orientation of
30   the respective end of the corresponding arm 11 are described with reference to the assigned joint 10 with the aid of which the arm 11 is connected to the preceding arm 11.

35   A hand surface 12 on which the tool 13 is fitted is located at the end of the chain of arms 11.

A TCP coordinate system $\tilde{O}_{TCP}$ that has an origin at the center point TCP of the tool is fixed for the tool 13.

TCP positional coordinates that define the position and orientation of the tool center point TCP with reference to the tool reference point W on the hand flange 12, that is to say with reference to the fastening point of

5   the tool 13 on the industrial robot 8, are provided for the tool 13 on the basis of this TCP coordinate system O_{TCP}.

In order to be able to calibrate the TCP positional

10   coordinates during operation with reference to the tool reference point W of the industrial robot 8 quickly and with a low output on computation, the tip of the tool 13 is moved into the DESIRED tool center point $TCP_{DESIRED}$ of the calibration apparatus 1, which is mounted in

15   stationary fashion, on the basis of the TCP coordinate system $\tilde{O}_{TCP}$. Consequently, there is an interpolation referred to the tool center point TCP, of the movement path during guidance of the tool 13 by the industrial robot 8. The origin of the TCP coordinate system $\tilde{O}_{TCP}$ is

20   thereby held in a stationary fashion with reference to the fixed TCP positional coordinates of the tool center point TCP.

Upon interruption of the first light barrier, the TCP

25   positional coordinates are fixed, and the deviation of the ACTUAL tool center point TCP_{ACTUAl} from the DESIRED tool center point $TCP_{DESIRED}$ is determined for the axis y. Correspondingly, upon interruption of the second light barrier the deviation of the ACTUAL tool center point

30   TCP_{ACTUAL} from the DESIRED tool center point $TCP_{DESIRED}$ is determined for the second axis z. Taking account of the fact that the two light barriers define a common plane that was traversed on the third axis x at the zero point, these deviations of the first axis y and the

35   second axis z correspond to the displacement of the tool center point TCP in three-dimensional space. The sequence of the interruption is determined by the tool bending and the traverse control.

The actual tool center point is determined by the center point between interruption and renewed release of a light barrier. In addition, the diameter of the tool can be determined for a duration of the interruption.

Thus, upon wear or bending of the tool 13 the displacement of the tool center point TCP can be determined directly in the TCP coordinates from the deviation, without an extended search for the crossing point R. A need to carry out complicated coordinate transformations is also eliminated.

Figure 4 shows the tool 13 with the TCP coordinate system $\tilde{O}_{TCP}$, of which the origin is at the center point TCP of the tool 13. In the case of the distortion of the tool that is sketched, the tool center point TCP_1 is displaced with reference to the previously fixed original tool center point TCP_0. The TCP positional coordinates are to be corrected by this displacement $\Delta TCP_0 = TCP_1 - TCP_0$ since, in accordance with the invention, the control of the industrial robot 8 is performed with reference to the TCP coordinate system $\tilde{O}_{TCP}$, the difference between the originally fixed TCP positional coordinates TCP_0 and the position of the new tool center point TCP_1 of a worn tool 13 is determined from the differences Δy upon interruption of the first light barrier for the y axis, and Δz upon interruption of the second light barrier for the z axis. Since the plane defined by the light beams arrives at x = zero, the deviation x can additionally be calculated with reference to the x value of the DESIRED tool center point.

Deviations of the tool length in the x direction can be determined, for example, by means of a second measurement travel by moving the tool into the light barriers that cross one another, doing so from above or below in the direction of the x axis.

If the light barriers do not coincide with the x, y and z axes, deviations in the direction of the x, y and z axes can be calculated from the known orientation of
5   the light barriers and the vertex angle α by means of coordinate transformation.